A Repository of Designs for Process and Assembly Planning

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Abstract

This paper provides an introduction to the Design, Planning and Assembly Repository available through the National Institute of Standards and Technology (NIST). The goal of the Repository is to provide a publicly accessible collection of 2D and 3D CAD and solid models from industry problems as well as related information for planning and assembly. In this way, research and development efforts can obtain and share examples, focus on benchmarks, and identify areas of research need. The Repository is available through the World Wide Web at URL `http://www.parts.nist.gov/parts`.

Keywords: Solid Modeling, CAD, Feature Recognition, Feature-based Manufacturing, Manufacturing Process Planning, and Assembly Planning.

1 Introduction

The Design, Process Planning and Assembly Repository is an effort at the National Institute of Standards and Technology (NIST) joining government agencies, industry, and academia to provide a library of example data for use by the research community. This data includes 2D and 3D designs and solid models, assemblies and process planning information.

This paper introduces the Repository and gives an overview of its contents and structure. It is the goal of the Repository to give researchers access to a wide variety of problems taken from industry—thus improving the base of common working knowledge for the community and giving students access to challenging and high-impact problems. The Repository will also provide a focal point for collaboration, allowing researchers to post challenge problems to a wide audience, share results, or perform larger-scale experiments requiring bigger data sets with industrially relevant data. It is our belief that establishment of this Internet-enabled communal library will hasten advances in solid modeling and application areas such as manufacturing process planning, feature recognition, and assembly planning.

The NIST Design, Process Planning and Assembly Repository is a focal point of several activities at NIST, including the NIST Process Planning Testbed[1] and the NIST Engineering Design Technologies Project.[2] The long-term goal of the Repository is to provide a comprehensive engineering knowledge-base that includes

[1] `http://www.nist.gov/msid/projs/pptb/homepage.html`.
[2] `http://www.nist.gov/msid/groups/edtg.htm`.

non-proprietary information including: designs, design histories, case studies, process and assembly plans, requirements documents, etc. This digital library will provide valuable information to the research and development community, as well as engineering and manufacturing firms in the United States and elsewhere.

The paper is organized as follows: Section 2 overviews the current status and content of the Repository, describing the manufacturing domains it covers and giving a number of examples. Section 3 discusses research issues that either emerged during development and population of the Repository and outlines some of the new problems which can be addressed based on the Repository's contents. Section 4 gives concluding remarks.

2 Background

Several efforts to build repositories of test cases, algorithms, and sample data have been undertaken by other academic research disciplines in recent years. Notable among these:

- The European Computational Geometry Algorithms Library (CAGL): `http://www.cs.ruu.nl/CGAL`.
- LEDA, a C++ Library of Efficient Data Types and Algorithms: `http://www.mpi-sb.mpg.de/LEDA/www/leda.html`.
- CMU Artificial Intelligence Repository: `http://www.cs.cmu.edu/afs/cs.cmu.edu/project/ai-repository/ai/html/air.html`.
- UCI Machine Learning Repository: `http://www.ics.uci.edu/~mlearn/MLRepository.html`.
- The Guide to Available Mathematical Software (GAMS): `gopher://gams.nist.gov`

The ascendency of the Internet and the World Wide Web has provided the communication medium to build vital online libraries having wide user-bases and access.

The NIST Design, Planning and Assembly Repository (`http://www.parts.nist.gov/parts`) has initially been designed to serve three communities:

- *Manufacturing Process Planning* has been an area of active research activity over the past 15 years. The two traditional types of approach to computer-aided process planning are the *variant approach* and *generative approach*. The variant approach involves retrieving existing plans for similar parts and making modifications to adjust the plan for new parts. Generative process planning creates new process plans using decision logics and process knowledge. For additional details and literature surveys on process planning, readers are referred to [1, 4, 27].
- *Feature Recognition and Feature-based Manufacturing* [19] has emerged as a critical enabling technology for a number of application areas in CAD/CAM, including process planning. In essence, product descriptions as geometry alone do not convey sufficient information for downstream manufacturing activities; hence, designs must be interpreted in terms of manufacturing features. *Automated feature recognition* has become the preferred technique for producing feature-based representations, having been employed with varying success for a variety of applications including process planning[26, 25], part code generation for group technology and design analysis [17]. These feature technologies rely heavily on the geometric and topological manipulation capabilities of solid modeling systems and deal predominantly with form or machining features.
- *Assembly Planning* has been approached as both a geometric and symbolic reasoning problem. Geometric reasoning applied to assembly planning has focused on motion planning, fixturing, and robotic as well as human grasping [13, 28]. Symbolic approaches emphasize the generation of assembly sequences

for individual components and sub-assemblies as well as on the development of rules and spreadsheets to help designers create more efficient assemblies [2]. Much of the existing geometric reasoning work operates on polyhedral approximations of the CAD data and on designs with uni-directional assembly plans.

The Repository supplies a large collection of CAD and solid models to serve as test cases for these new technologies. Although significant progress has been made on many research fronts, at present there are no fully automated process planning, feature recognition or assembly planning systems for other than very specific problems. Complicating matters is that most previous research efforts have proceeded individually—each focusing on some particular sub-domain with its own idiosyncratic examples. Organizations such as Computer Aided Manufacturing International (CAM-I) have put forth suggestions for benchmarks and example parts on a number of occasions, however current trends require a more efficient mechanism for collecting and disseminating example cases. The Repository will be a means of focusing these efforts.

3 Description of Repository Contents

The Repository contains models of parts and assemblies covering a variety of commonly used manufacturing processes. Many of these parts are taken directly from industry or government efforts and describe artifacts whose manufacturing plan might include several different processes. At the time of this writing, the current content of the Repository includes nearly 2500 part models in a variety of formats.

For a few of the examples of machined parts, the Repository contains machining features information as well as a limited number of process and operation plans. The process planning information is from various projects at NIST; the features information has been contributed by several research groups around the world. As yet the repository does not contain any industrial process plans—such “real” process plans are often considered to be highly valuable intellectual property and companies are reluctant to part with them.

3.1 Data Exchange Formats

All of the models in the repository are stored in at least one format that is either an established international standard or industry-developed 'open' standard:

`.stp/.step` STEP Application Protocol 203 (AP 203) is the International Organization for Standardization (ISO) standard 10303-203 for the exchange of boundary representation solid model of mechanical artifacts [8]. Various levels of STEP AP203, as of 1996, are beginning to become a common import/export option in high-end and mid-priced CAD/CAM systems.

`.igs/.iges` The Initial Graphics Exchange Specification (IGES) format [14]. Originally only for the exchange of 2D and 3D wireframe, recent IGES extensions include surface information.

`.sat` Spatial Technologies' ACIS solid modeler file format [23].

Some of the Repository's content is maintained in a number of proprietary native CAD/CAM file formats:

`.acs/.acis` The ACIS kernel ships with a self-contained *test harness* [21]. The test harness is an interactive text-based interface to the functionality of the ACIS kernel, allowing users to create scripts that create, manipulate, and save/retrieve models. `.acs` and `.acis` files are scripts for generating ACIS bodies within the test harness.

`.dgn` The design file format for Bentley Systems Inc. MicroStation and MicroStation Modeler CAD system. The `.dgn` file format represents 2D and 3D surface and wireframe data (as designed in the MicroStation CAD system), as well as 3D solid model data (for artifacts designed in the ACIS-based MicroStation Modeler system).

`.dxf/.dwg` The design file format for Autodesk's AutoCAD system. Similar to Bentley's MicroStation environment, `.dxf/.dwg` files for earlier AutoCAD releases (V12 and earlier) contain 2D and 3D surface and wireframe data. Recent releases of AutoCAD (V13 and the Mechanical Desktop) are ACIS-based products supporting solid models.

`.kid` The Parasolid modeling system includes an interactive programming environment based on LISP. The Kernel Interface Driver (KID) is a runtime environment for generating solids and interacting with the Parasolid modeling engine. `.kid` files are LISP programs that run in the KID.

`.pfi` PADL-2 [3] is an early solid modeling system that came out of research at the University of Rochester. PADL files are LISP-like in structure and define the CSG tree for the artifact they describe.

`.prt, .neu, .asm` Pro/ENGINEER (from Parametric Technology Corporation) uses several of its own internal and exchange file formats. The Repository contains examples in several of these. `.prt` is the 'part' file format—often containing a history tree of modeling operations and dependencies. This is a format close to Pro/E's internal data model.

`.neu` is a Pro/E 'neutral file'—a text-based description of the geometry and topology of an individual Pro/E solid model. This is the model format Pro/E-compatible systems often employ for import and there are a variety of commercial translators to exchange `.neu` with other CAD formats.

`.asm` is Pro/E's model for assemblies. Often the assembly models consist of references to several individual `.prt` files; they can also contain links or copies of the individual part files (for those that appear multiple times in an assembly).

`.scm` A companion modeling product to ACIS is the 3D Toolkit [22]. The 3D Toolkit is a set of libraries extending the functionality of the ACIS kernel, as well as an interactive programming environment based on the Elk Scheme Interpreter [7]. `.scm` files contain Scheme programs that run in the 3D Toolkit environment.

`.tsb` The 3D-EYE TriSpectives workbook file format, describing ACIS-based 3D models along with visualization information.

`.xmt/.xmt_txt` Parasolid [20] Transmit Files contain the geometry, topology, and attached data for solid models created with the Parasolid solid modeling system from Shape Data Limited. Parasolid is a stand alone solid modeling kernel and programming library as well as the modeling engine for the Unigraphics CAD/CAM system of Electronic Data Systems (EDS).

The above is a list of the file extensions for solid models and CAD models in the repository at the time of this writing. It is not meant to be an exhaustive list of data exchange formats, nor a set of recommendations.

The Repository also contains a number of image and display formats for model files, including:

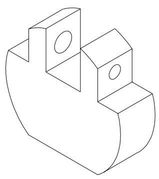
`.gif` CompuServe Graphical Image Format;

`.pdf` Adobe Portable Document Format;

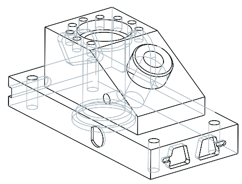
`.ps/.eps` Adobe PostScript format;

`.wrl` Virtual Reality Modeling Language format (VRML version 1.0) from Silicon Graphics Incorporated, as produced by 3D Eye's TriSpectives 3D drawing tool.

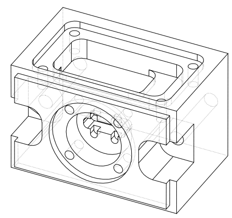
While these formats do not convey product data in any way other than through a picture or 3D scene, they are increasingly becoming part of documents in multimedia engineering environments.



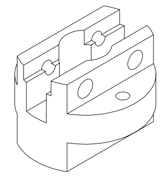
(a) A simple bracket example from [9, 17].



(b) The ANC101 test part from the CAM-I consortium.

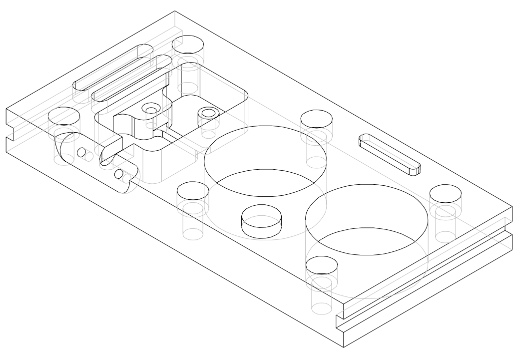


(c) A part with a number of different types of feature interaction.

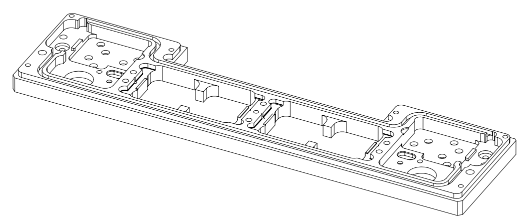


(d) An example from [18, 17] of a design of a socket, along with solid models for the part, stock, and delta volume.

Figure 1: Several examples of machined parts in the Repository.



(a) A solid model of a benchmark part for the United States Department of Energy's TEAM Program (Technologies Enabling Agile Manufacturing). This solid model describes a part requiring multiple set-ups with numerous interacting planar, cylindrical and conical surfaces.



(b) This solid model of a machined contains 419 planar, cylindrical and conical surfaces and illustrates some of the complexities inherent in real world artifacts.

Figure 2: Parts from Allied Signal Corporation.

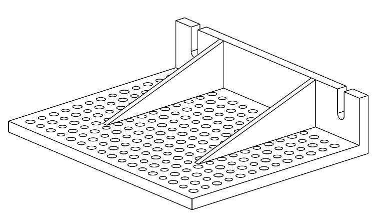


Figure 3: A fixture from ICEM/Technomatix's PART system.

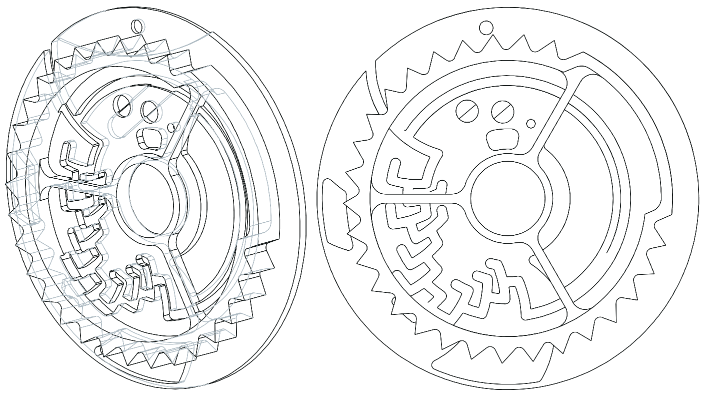


Figure 4: The Maze Wheel used in the Discriminator from Archimedes Mechanical Assembly Planning System [12].

3.2 Machined Parts

Machining has been among the most widely addressed manufacturing process in research on computer aided manufacturing and process planning. The Repository includes many parts which were designed to be manufactured by machining processes, including many examples from previous research work in the area.

UMD Bracket Figure 1 (a) shows a simple bracket example from the University of Maryland. It has a limited number of features with fairly discrete interactions. This part is available from the repository in the directory `UMD/simple_bracket.sat`.

CAM-I ANC101 Part Figure 1 (b) shows the CAM-I ANC101 test part, originally created to be a test case for solid modeling systems and early process planners. From both a feature recognition and process planning standpoint, the part is fairly straightforward as (1) the features are mostly holes and pockets and (2) there is very little interaction among the features. This part is available at `NIST/Pete_Brown/anc101.sat`.

NIST Demonstration Part I Figure 1 (c) shows an illustration of a demonstration part used in the Process Planning Applications Project at NIST. This part, while straightforward for both feature recognition and planning, can produce problems dependent on the set of manufacturing resources being used to execute the process plan. Specifically, choice of a cutting tool assembly for machining the holes must take into account the depth and size of the pockets as well as the intermediate workpiece in order to avoid interference with the part.

This part has been used as an example by several research groups [24, 15], with interestingly different results illustrating the variation in how research problems have been defined. This part is available at `NIST/new_demo.sat`.

UMD Socket Figure 1 (d) shows the socket example from [18, 17] . More interesting than the bracket, it has approximately two dozen features (depending on the approach to feature recognition employed) and several non-trivial feature interactions. This part is available at `UMD/simple_bracket.step`.

DOE TEAM Part Figure 2 (a) shows an example part being used in the United States Department of Energy's TEAM Program. This part is similar in complexity to the UMD Socket, with several dozen feature instances, several setups, and a few non-trivial interactions. This part is available at `Allied_Signal/team.step`.

Allied Signal Part12 Figure 2 (b) is a part provided by Allied Signal's Kansas City Plant and it shows several magnitudes of complexity greater than the above examples. This part, with over 400 surfaces, has hundreds of features with dozens of interactions. While most of the feature instances are simply machined holes and pockets, the quantity of them creates a difficult geometric problem. This part is available at `Allied-Signal/part12.step`.

The WINKEL Figure 3 shows a fixture from the ICEM/Technomatix PART [6, 25] process planning system. It has several hundred feature instances, most of which are simple holes. This part is available at `ICEM-CDC/demos/WINKLE.sat`.

The Maze Wheel Figure 4 is the main maze wheel for the mechanism of the discriminator, described in the next section and shown in Figure 5 (c). The maze wheel is a machined part with a design that had to take into account balance and be of minimal weight—resulting in the intricate design. This part is available at `Sandia/Randy_Wilson/discrim/thru-mazewheel.sat`.

The preceding is not a complete list of the available machined parts at the time of the current writing.

3.3 Assemblies

Assembly modeling and assembly planning is an area of great economic concern in industry. Many tools and approaches developed in the research community pertain to only narrowly focused domains. The Repository contains a variety of assembly models, some from vendor demonstrations and others from real products. We describe below several examples.

The Spectrometer Figure 5 (a) illustrates the design of a variable radius Spectrometer to be attached to an x-ray source in a vacuum. The detector on the instrument is a position-sensitive device for recording and measuring highly ionized spectra. This assembly is available at `NIST/Manfred_Osti/spectrometer/`.

The Vacuum Suitcase Figure 5 (b) shows the design of a Vacuum Suitcase for the transport of VLSI chips among different fabrication facilities. Made of mostly standard catalog components, the Suitcase is a prototype to enable silicon wafers to be processed by multiple facilities. This assembly is available at `NIST/Manfred_Osti/suitcase/`.

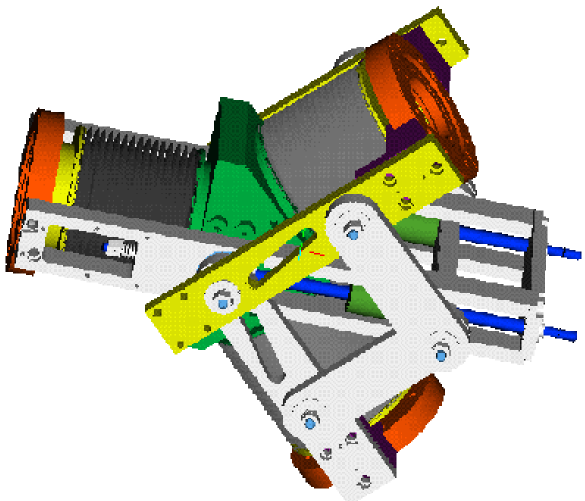
The Discriminator Figure 5 (c) shows the Discriminator—a safety device designed to allow operation of a system only when the system has been given a particular code. If dropped or exposed to fire, electrical shorts, crashes, etc. the discriminator locks up, preventing operation of the system and requiring it be disassembled before operating again.

This part is courtesy of Randy Wilson and Sandia National Laboratories and is available at `Sandia/Randy_Wilson/discrim/`. The discriminator was used to test Sandia's Archimedes assembly planning system [12].

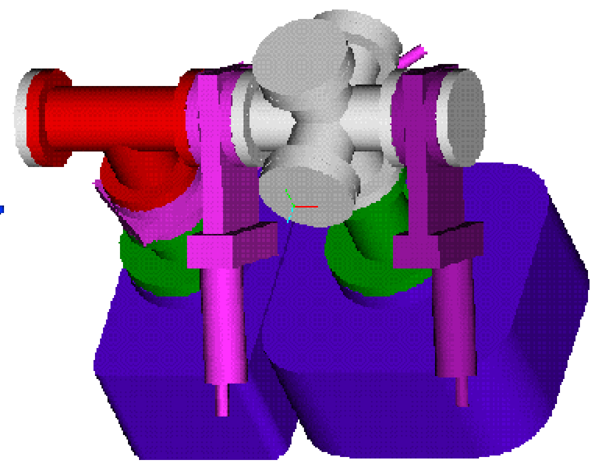
3.4 Other fabrication processes and multi-process Parts

In practice, the percentage of parts which are exclusively machined is relatively small. In the manufacturing enterprise, the vast majority of artifacts are acted upon by more than one manufacturing process. For example, parts are produced by casting and then machined to achieve final tolerances. Sheet metal parts are punched and drilled prior to being bent. A severely complex problem is the interactions among the individual components in an assembly of machined parts—where optimization of manufacturability requires a careful balance between the needs of assembly ease with the often opposing needs of the machining process.

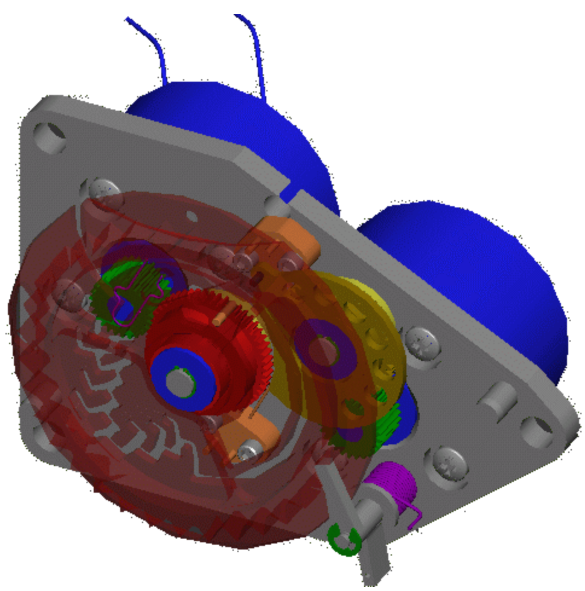
Sheet metal part Figure 6 illustrates a simple sheet metal part with several bends. This part is available at `ACIS/Spatial/blech.sat`.



(a) The Spectrometer.



(b) The Vacuum Suitcase.



(c) The Discriminator.

Figure 5: Several models of full assemblies from the Repository.

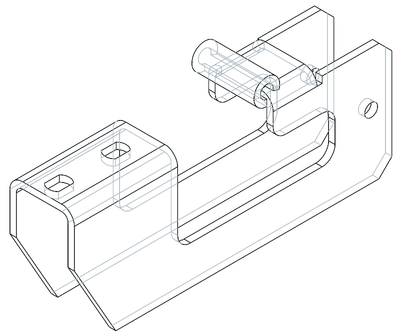


Figure 6: A simple sheet metal part.

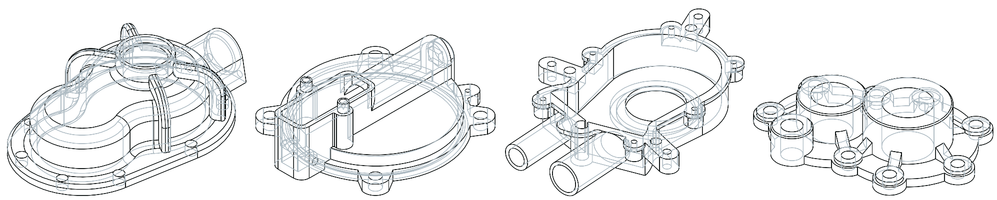


Figure 7: Several parts that are cast and subsequently machined.

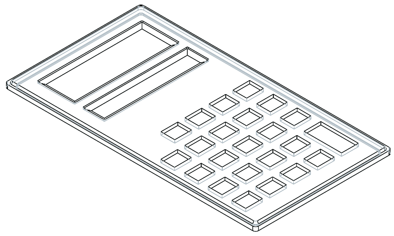
Cast parts Figure 7 shows several parts which are manufactured primarily by casting, with machining as a secondary process. For these types of parts, which are very common in industry, the machining operations for these parts are beyond the scope of any existing process planning system for machining. From a feature recognition viewpoint, such parts pose tremendous difficulties to algorithms based on polyhedral parts or approximations. These parts are available at `ACIS/Spatial/cognit.sat`, `ACIS/Spatial/cover.sat`, `ACIS/Spatial/pump.sat`, and `ACIS/Spatial/cover2.sat` respectively.

Injection molded parts Figure 8 (a) shows a simple calculator cover manufactured by injection molding. This part is available at `ACIS/Spatial/calc.sat`.

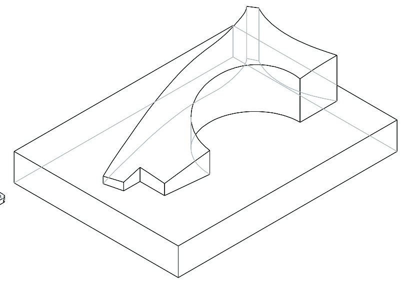
A stamping die Figure 8 (b) shows a die used to stamp fenders for automobiles. This die is basically a large machined part with a higher-order surface describing the shape of the fender. In the context of current literature, this example presents several open questions: What are the features (if any, or is it just one feature)? Is process planning in this case merely the generation of the cutter paths? This part is available at `ACIS/Spatial/fender.sat`.

The Torpedo Motor Figure 9 (a) shows a model of a housing for a torpedo motor: a precision sand casting that is subsequently machined. Figures 9 (b) and (c) show the casted stock material and the delta-volume, respectively. This part is available at `NIST/Pete_Brown/Torpedo_Motor/`.

The Unterlafette Figure 10 shows another famous benchmark part from CAM-I. The Unterlafette is a large mounting for holding the turret and cannon of a heavily armored tank. The model of it in the Repository represents it as a single solid model. To manufacture it in practice however, the Unterlafette consists of many large machined parts, assembled and welded together. This part is available at `ACIS/Spatial/unter.sat`.



(a) A plastic cover for a calculator, manufactured by injection molding.



(b) A stamping die for manufacture of a automobile fender. This part is available at `ACIS/Spatial/blech.sat`.

Figure 8: Parts for mixed manufacturing processes.

3.5 Some Pathological Examples

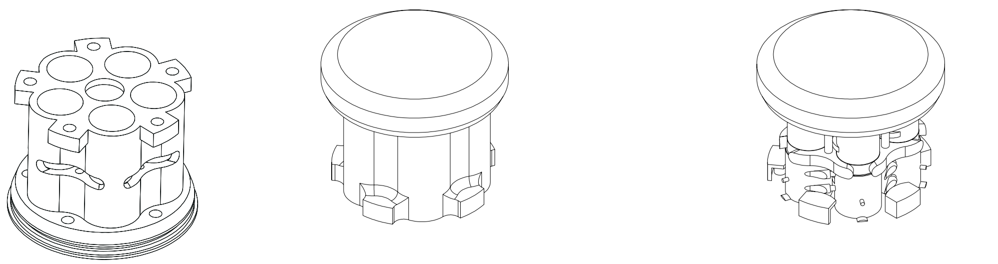
In addition to designs of real artifacts, the Repository also has numerous examples which capture geometric configurations which are pathologically difficult for process planning and feature-based manufacturing. In these cases, the solid models themselves do not necessarily represent realistic (or even manufacturable) artifacts—rather they attempt to capture boundary conditions on the current state-of-the-art commercial and research systems. In the case of feature recognition and process planning, most of these pathological examples describe configurations which are unmanufacturable. Such examples can be used to determine if systems return false-positives—i.e., if they find plans or features for parts for which no manufacturing plan is possible.

Several examples are described below, primarily in the context of feature recognition and feature-based process planning for machining.

Unmachinable holes. The part in Figure 11 (a) illustrates a configuration where local geometry and topology information indicates the existence of an array of drilled flat-bottomed holes that are not through holes. However, in most every reasonable machining situation, this part is unmachinable because the holes are inaccessible—to orient a drilling tool to make the hole would require it intersect with the solid model of the final part. It should be noted that this part can be manufactured (for example, if the part is treated as an assembly, with the holes drilled and components welded). This part is available at `UMD/unmachinable_holes.sat`.

The bottomless pocket. Figure 11 (b) shows a part with a bottomless pocket feature. In such a feature configuration, the algorithm for finding and locating the profile of the pocket might prove difficult to capture with basic geometric rules.

Where is the profile? When two or more distinct features interact, individual feature instances can become distorted and information vital for reasoning about them (or recognizing them) can be eliminated. Figure 11 (c) shows an example of a solid model of a mechanical part containing a number of feature interactions. In this case the best manufacturing plan might include milling the x-shaped pocket or considering it as two distinct slotting operations. However, in either case, there are no faces left in the part from which to infer how to create the walls of these features. In this example, however, the CAD model of the part does not seem to provide sufficient information from which to generate this volume. This type of example is



(a) Feature-base part model

(b) Model of pre-cast stock

(c) Model of the delta volume

Figure 9: A model of a housing for a torpedo motor: a precision sand casting that is subsequently machined. This part is available at `NIST/Pete_Brown/Torpedo_Motor/`.

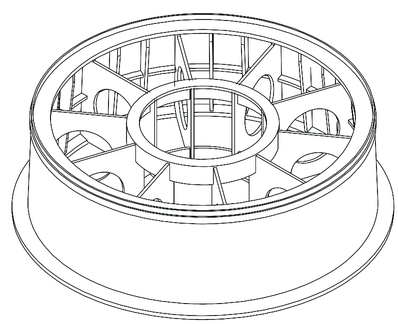


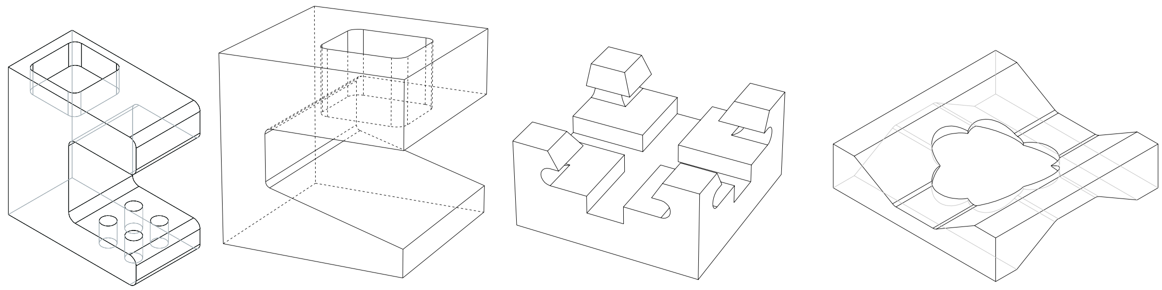
Figure 10: The Unterlafette: a large-scale part requiring machining, assembly, and welding.

particularly problematic for graph-based feature recognition methods. In graph-based approaches, the graph structures used to find features are built from the boundary representation information for the artifact and, in this case, the basic boundary model does not explicitly contain the information needed to find the features that are likely to occur in the most practical manufacturing plan.

Pathological configurations. The part in Figure 11 (d) provides an example which, while machinable given the correct tooling, contains a number of pathological feature interactions. In particular, note that the clover-shaped pocket through the center is composed of a ring of partial cylindrical surfaces. If each of these are assumed (by an automated planning system or feature recognizer) to be machined holes, there is a non-empty volume in the center of the pocket that is not described by a machining operation[3]. This part is available at `UMD/clover_part.sat`.

Conflicts arising from tolerances and surface finish. Figure 12 from Gupta [9] shows a part with two drilling features, holes h_1 and h_2, requiring a tight concentricity tolerance. In this case the hole is

[3]From a geometric point of view, this hanging volume would just 'drop out' after the holes are machined. In practice, however, this indeterminacy would not be desired as this hanging piece could easily damage tooling or fixtures. Further, common machining practice would caution against creating these cylindrical surfaces as holes, as it would require the holes be drilled through areas already partially machined—thus increasing the chance of tool damage or fracture.



(a) A part with un-machinable holes.

(b) Bottomless pocket.

(c) Missing profile.

(d) A part with interacting angled slots and holes, with a clover-profiled pocket.

Figure 11: Several pathological examples for process planning and feature-based manufacturing.

too long to be drilled in with a single drilling operation (the length/diameter ratio is too large). Further, the interaction among the tolerances of the holes creates a manufacturability problem: drilling h_1 and h_2 with two operations at different setups will make the tolerances unachievable. This part is available at `UMD/unmachinable_ex1.sat`.

4 Repository Interface

The Repository is available through the World Wide Web (WWW) at Uniform Resource Locator (URL) `http://www.parts.nist.gov/parts` and via anonymous ftp at `ftp://www.parts.nist.gov/parts`. Figure 13 (a) shows the Repository home page. The Web interface allows users to navigate through the collection of parts and to perform searches for parts meeting certain criteria. For each part in the Repository, a brief description, where available, is provided along with pointers to the part in its available formats.

When navigating the Repository, the interface provides links to subdirectories and parts in each directory. Figure 13 (b) shows the navigator at the top of the Repository. Clicking on a subdirectory will move the navigator down into that directory. Figure 13 (c) shows the result of following the `Allied-Signal` link.

This directory contains a number of part models. Following these links, the user is provided with a page of detailed information for the given part. Figure 14 (a) shows the information displayed for the `3tmount` part. The display includes information about the part describing the contributor and the types of manufacturing processes which will be used to fabricate the part. The interface provides a table of links to the formats this file is available in. Most of the solid models are available in both ACIS `.sat` and STEP AP203 formats; with some models available in Parasolid `.xmt/.xmt_txt` format . Pictures of the part are also available in Postscript, GIF and X11 bitmap.

Other types of information are available for some parts. In Figure 14 (b), the user has brought up a virtual reality browser to view a part with an associated Virtual Reality Modeling Language (VRML) file.

The Web interface provides the ability to search for parts in the Repository based on certain criteria. Figure 14 (c) shows the user interface for searching the Repository. Currently, the user can search for parts based on particular contributors, manufacturing process types and available file formats. As the Repository grows, more search parameters will be added. For each parameter, the user selects the options of interest. Multiple selections for a given parameter will be "or"ed together. If no selections are made for a given parameter, the parameter is not used to restrict the search. After submitting the query, a list of parts matching the query are returned allowing the user to bring up a detailed information page on each part,

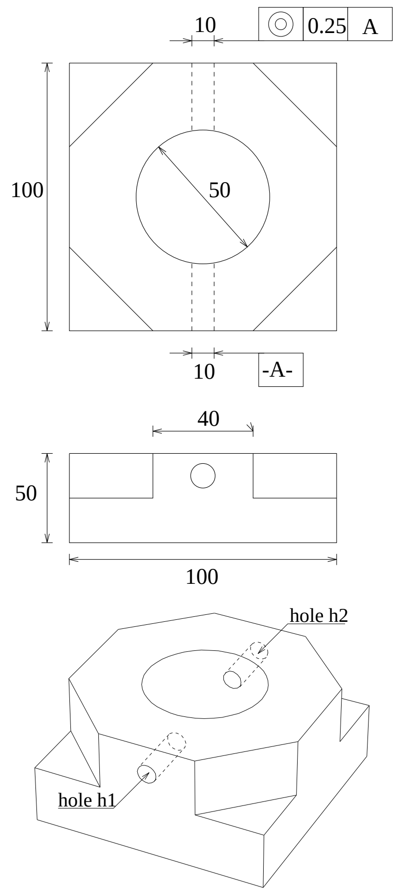


Figure 12: An Example of a design with dimensions and tolerances that cannot be achieved on a 3-axis vertical machining center (from [9]).

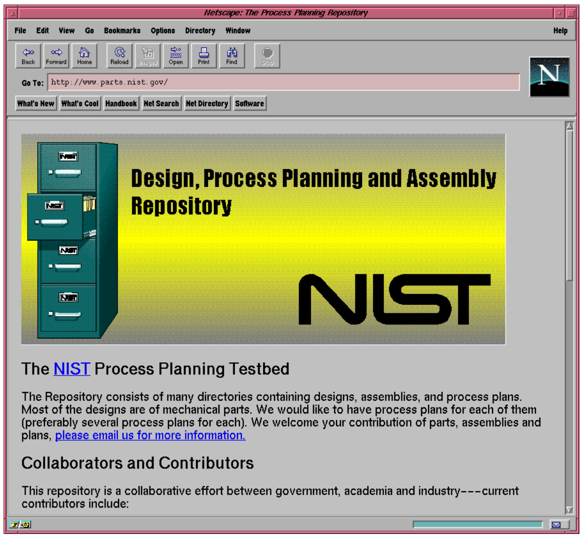
such as the one in Figure 14 (a).

5 Open Research Issues

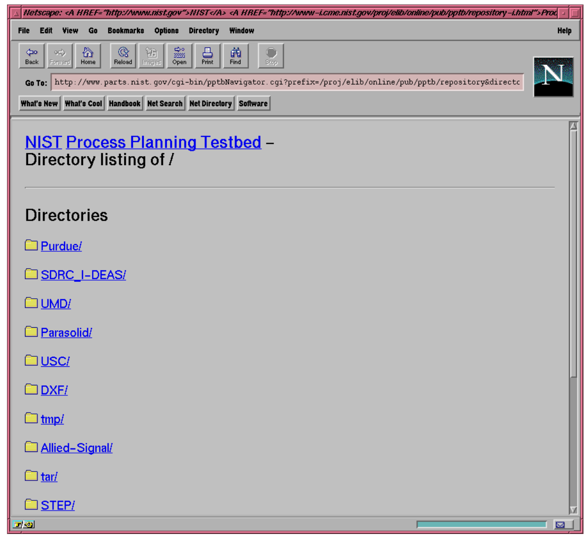
The deployment of this publicly accessible library, in addition to providing a vehicle through which researchers can share their results, enables many exciting new research problems to be addressed. We present below a brief list of several of the most immediately approachable.

Development of Smarter Part Libraries. Part libraries and catalogs have been an area of active study and development by the standards community [11, 16] and internal to organizations using product data management (PDM) tools and databases. Delivering smarter part databases will require augmenting designs with design history and functionality information, behavioral features, and other semantics. Developing algorithms to intelligently act on such databases and retrieve parts based on similarity requires access to realistic example data.

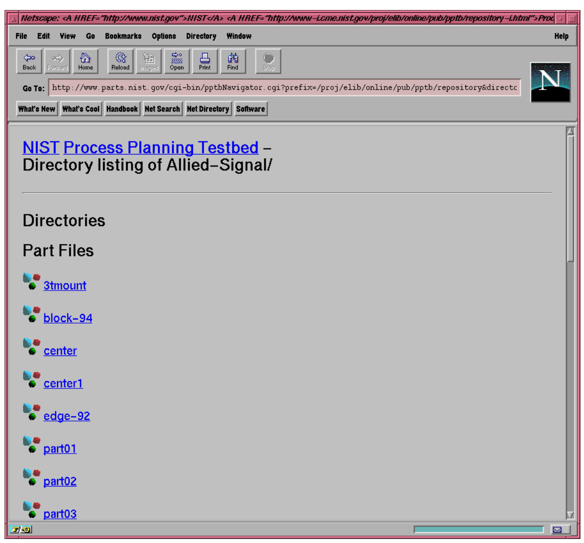
CAD/CAM problem classification. Developing general measures of the difficulty of application-level problems involving solid modeling is a largely unexplored area of study. For example, a given part may



(a) NIST Repository home page.

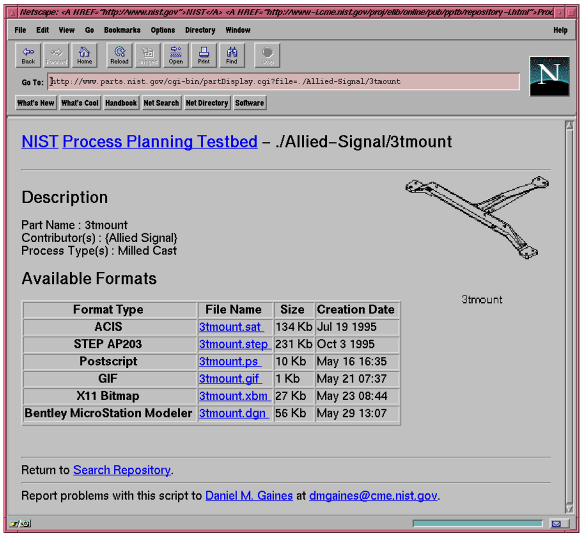


(b) Navigator at top directory.

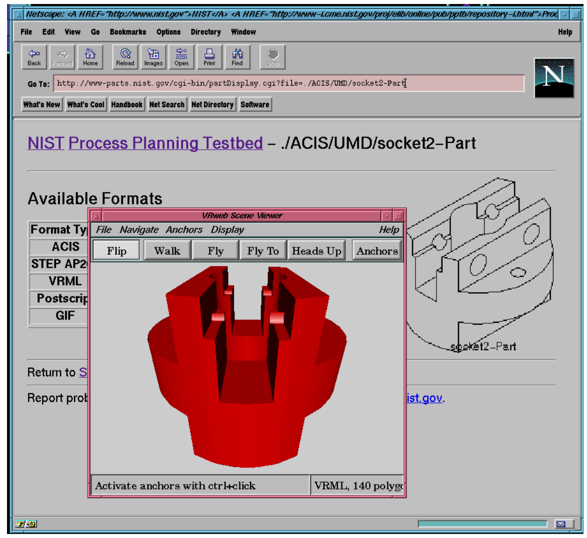


(c) Navigator in `Allied-Signal` directory.

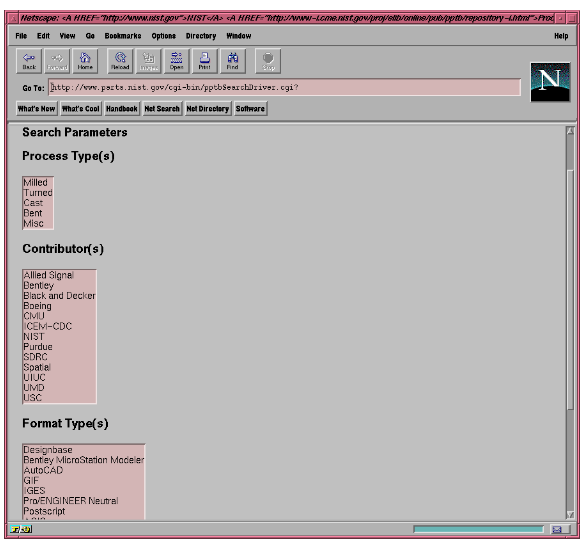
Figure 13: Navigation through the NIST Repository



(a) A sample part description, including a count of the number and type of surfaces in the part.



(b) The VRML model for the UMD Socket.



(c) The basic search interface in the current version of the NIST Repository.

Figure 14: Other aspects of the Repository interface.

pose a challenge for feature recognition, process planning, part production or assembly. Determining, for a given solid modeling application domain, where the complexities and pitfalls lie is vital in order to determine where the research problems are. The wide variety of parts in the Repository provides the opportunity to study these questions initially in the areas of feature-based manufacturing, assembly and process planning.

Production-ready Feature Recognition and Process Planning. Most existing work on feature recognition has focused on narrowly defined application domains, most often machining and usually limited to polyhedral parts. One goal of this Repository is to provide a supply of real-world parts with which to challenge the existing-state of-the-art. The scope and scale of the examples in the Repository exceeds the abilities of all known commercial and research-level feature recognizers.

For Computer-Aided Process Planning for machining and assembly, the state-of-the-art is similar—there exist several automated and semi-automated tools for focused domains. While great advances have been made in solving these well-defined fundamental problems, large issues about the scalability of approaches and the applicability of existing techniques to different domains remain open.

Process-independent design and Process-driven redesign. Existing designs may have to be modified for changes in the factory, in regulations, or performance needs. Process-independent design is the activity of designing a product without consideration of any one specific manufacturing process—often postponing the final detailed design until the last minute when it can be mapped to the best available technique at that time.

Process-driven redesign concerns the problem of how to re-design parts based on changes in manufacturing decisions. For example, if batch sizes increase for a machined part, casting can become a more economical possibility—in which case the part must be re-designed for the new process.

The current Repository includes many non-trivial examples of parts from a number of different manufacturing processes to further enable study of how to build software support tools for these tasks.

Planning for multiple manufacturing processes As noted earlier, many parts are manufactured with multiple manufacturing processes, casting-then-machining being a common combination. Very little work has gone into how to effectively plan for the manufacture of these types of common artifacts. Integration of planning systems for different manufacturing domains and study of trade-offs among the processes requires a large and varied dataset. The parts in Figure 7 and the Torpedo Motor of Figure 9 are beyond the capabilities of existing systems research and commercial systems, both in terms of their geometric and process complexities.

6 Conclusions

The development of a common collection of realistic CAD/CAM data and parts is of critical importance for the research and development community. The lack of such a collection has been a significant impediment to building consensus on technical issues and research directions—often resulting in redundant research effort and excessive overlap. To address this, a Design, Process Planning and Assembly Repository has been created at NIST by researchers in engineering design and process planning. Our long-term goal of the Repository is to provide a comprehensive engineering knowledge-base of designs, design histories, case studies, process and assembly plans, requirements documents, etc. to service the engineering and manufacturing community in the United States and elsewhere. The deployment of this publicly accessible library enables many exciting new research problems to be addressed.

There are several current limitations of the Repository's content. First, most of the example parts and problems are taken from either the academic research community or from the CAD/CAM software vendor community. Of these, the currently available industrial examples are mostly demonstration parts. While these are much more realistic than the academic examples, they still fall far short of the complexity of the parts in the current generation of commercially manufactured products. In one example from recent literature, Hardwick et al. [10] gives an example of a transmission assembly that occupies gigabytes of memory.

The second limitation is that information sets associated with the examples themselves are not very rich. For example, most of the solid models (in `.sat, .step, .dxf/.dwg/.dgn`, etc. formats) do not include manufacturing tolerance information, assembly relationships, information about functionality, design intent, kinematics data, parametrics and constraints, etc. There are a number of reasons for this deficiency, chief among them is the lack of agreed upon standards for representing and sharing this data. Further complicating matters is that, for attributes describing functionality or designer's intent, there are many open research issues regarding precisely what information should be represented.

A third caveat on the Repository is to note that the majority of the current contents are drawn from the mechanical design and manufacturing domain. This in no way should confine the future scope of the Repository—which might include other types of design data drawn from other domains of Computer Aided Engineering (for example, CAD data from Architecture, Engineering, and Construction (A/E/C)).

Even in its current form, we anticipate that the Repository can serve as a prototype collaboration [5] environment for researchers in these diverse areas and create a number of synergies. Active use of the Repository will greatly enhance its content, its value as a global resource, as well as benefit the research of those who use it. It is hoped that the establishment of this Repository, and its growth through the contributions of industry and academia, will lead to quicker advances on problems in engineering design and manufacturing automation.

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